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Specialized Diffractive Optics

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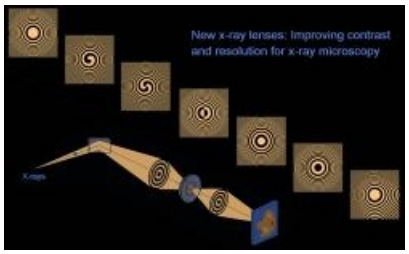

Specialized diffractive optical elements are being developed to improve contrast and resolution for imaging studies in the soft x-ray region. The techniques are developed at the spatially coherent soft x-ray test station, the full-field soft x-ray microscope XM-1, and the CXRO nanofabrication facility and can be extended for use with compact sources. Both lens based imaging methods utilizing unconventional zone plates and lens-less imaging methods employing improved reference objects are being pursued.

For high resolution lens based imaging, three classes of zone plates are being studied:

- spiral zone plates,
- Zernike zone plates, and
- wavefront coded zone plates.

Each of the optics, serving as the single objective lens in the imaging system, performs both the imaging and an additional image processing capability. For example, the spiral zone plates provide a method to image the object's local gradient of refractive index, being sensitive to changes in both phase and amplitude in a specimen. The Zernike zone plates allow soft x-ray Zernike phase contrast imaging without the use of an additional phase ring, and the wavefront coded zone plates allow depth of field extensions for high resolution three dimensional imaging. In addition, resolution and signal to noise improvements for lens-less imaging methods, such as holography, are being made through the use of the uniformly redundant array.

For more information, please see the publications.

Spiral Zone Plate Microscopy

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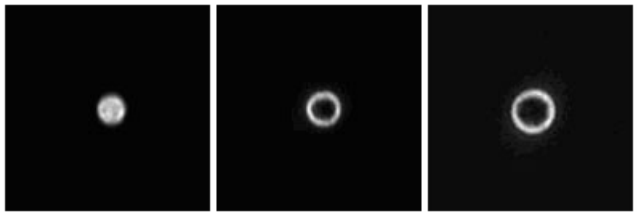
Spiral zone plate (SZP) microscopy has been demonstrated at the coherent soft x-ray test station. Images of a gold pinhole were taken using a regular zone plate, charge 1 SZP, and charge 2 SZP. Edge enhancement as expected is seen in the cases of the SZP images.

Fig. 1: (a) SEM image of a charge 1 SZP, (b) SEM image of a charge 2 SZP, and resulting images of a gold pinhole taken using a (c) Regular zone plate, (d) Charge 1 SZP, (e) Charge 2 SZP.
(Click on an image to view the full-size version)

(a) (b)



(c) (d) (e)

Uniformly Redundant Arrays

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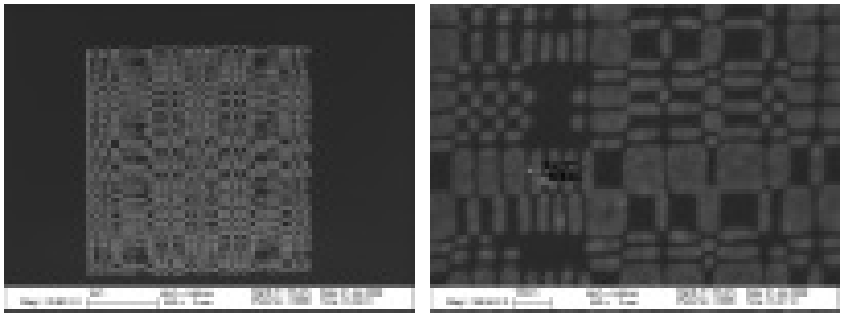
Holography performed with uniformly redundant arrays (URA) increase the signal to noise ratio of the holographic signal, which is especially important for high resolution holograms. It can be thought of as a type of multi-reference feature (as seen in figure 4) with the highest possible resolution proportional to the smallest feature sizes on the URA. High resolution URAs have been fabricated and are shown below. Experiments to perform high resolution holography using these URAs are underway.

Fig 4: (left) SEM image of a high resolution uniformly redundant array (URA) to be used as the reference structure for high resolution soft x-ray holography, (right) a zoomed-in version of the URA structure detailing the small gap sizes allowing for high resolution. (Click on an image to view the full-size version)



Wavefront Coded Zone Plates

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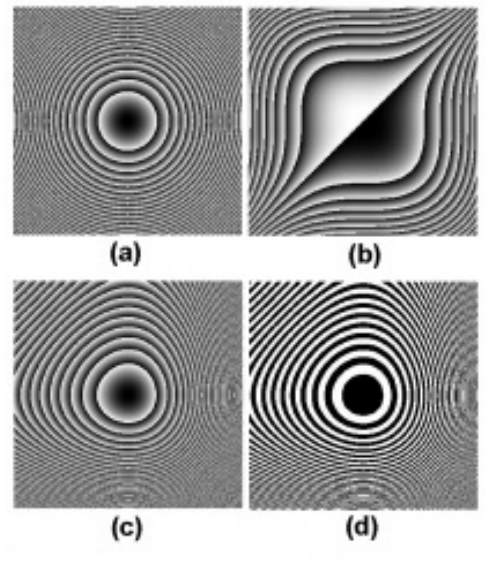
Wavefront coded zone plates (WCZP) are being used to extend depth of field in the full-field soft x-ray microscope. Currently, WCZPs with a cubic phase
(as shown in figure 3) have been made and experiments at the full-field soft x-ray microscope
are being performed.

Fig. 3: Simulations used in the design of the wavefront coded zone plates (WCZP) (a) a regular zone plate, (b) cubic phase, (c) combination of the regular zone plate and the cubic phase to make the WCZP, (d) a binarized version of the WCZP. (Click on the image to view the full-size version)



Zernike Zone Plates

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Zernike phase contrast has been demonstrated using both a positive zernike zone plate
(PZZP) and a negative zernike zone plate (NZZP) at the coherent soft x-ray test station. Images of a Cr test sample are shown in Fig.

2 with the corresponding zone plate used. Both contrast enhancement in the case of the PZZP and contrast reversal in the case of the NZZP were demonstrated.

Fig 2. (a) SEM images of a regular zone plate (RZP), positive zernike zone plate (PZZP), and negative zernike zone plate (NZZP) along with corresponding images of a chromium grating test sample (b). Lineouts are shown on the graph to the right. (Click on an image to view the full-size version)